

CONTINUOUS SPEECH RECOGNITION APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention relates to a continuous speech recognition apparatus and method, and more particularly to a continuous speech recognition apparatus and method which achieves augmentation in speed and accuracy of recognition.

Description of the Related Art

10 As an example of a conventional continuous speech recognition apparatus, reference is had to a paper by S. Ortmanms, "LANGUAGE-MODEL LOOK-AHEAD FOR LARGE VOCABULARY SPEECH RECOGNITION", ICSLP, 1996.

15 The conventional continuous speech recognition apparatus is shown in FIG. 6. Referring to FIG. 6, the conventional continuous speech recognition apparatus shown includes a hypothesis storage section 1, a hypothesis expansion section 3, a tree structure dictionary storage section 4, a language model section 7, and an acoustic model section 8.

20 In operation, the hypothesis storage section 1 stores hypotheses therein. The tree structure dictionary storage section 4 stores words, which make an object of recognition, as a tree structure dictionary (refer to FIG. 2). The acoustic model section 8 calculates an acoustic model score for each
25 frame. The language model section 7 calculates a language model score.

The hypothesis expansion section 3 acquires, for each frame, a structure of arcs from the tree structure dictionary storage section 4 taking an acoustic model from the acoustic model section 8 and a language model score from the language model section 7 into consideration and expands a hypothesis present on an arc to a succeeding arc. Referring to FIG. 2, a tree structure dictionary is structured such that a word is reached by tracing arcs branching in a tree structure from a root to a leaf (terminal arc).

Speech which makes an object of recognition is divided into short-time frames of a predetermined period, and such expansion as described above (that is, expansion of a hypothesis on an arc of a tree structure dictionary to a succeeding arc) is repeated from the speech beginning frame to the speech terminating frame. Then, a word through which a hypothesis which exhibits the highest score has passed in the past (a terminal of the tree structure dictionary) is finally determined as a recognition result.

Here, a hypothesis has position information of an arc on a tree structure dictionary, a history until the position is reached, and a score.

In a continuous speech recognition system wherein a plurality of words are represented as one tree structure dictionary (refer to FIG. 2), what is a word with regard to which a hypothesis is being expanded at present cannot be specified except at the terminal arc.

Therefore, although an acoustic model score is calculated for each frame, a language model score can originally be determined only when a hypothesis reaches a terminal arc of a tree structure dictionary.

5 Therefore, in order to add a language model score as early as possible, a method employing look-ahead of a unigram language model score and look-ahead of a bigram language model score is disclosed in the document mentioned hereinabove.

10 According to the look-ahead of a unigram language model score, the highest one of unigram language model scores of words settled at terminal arcs in a tree structure dictionary is provided to a predecessor arc, and the unigram language model provided to the arc is temporarily added as a language model score of the hypothesis present on the arc, and then, when the
15 hypothesis reaches the terminal arc of the tree structure dictionary and the word is settled, the unigram language model score which has been used till then is abandoned and then the settled bigram language model score is added.

20 On the other hand, according to the look-ahead of a bigram language model score, when a context is determined and a new tree structure dictionary is produced, bigram language model scores regarding all words of the context are calculated, and that one of the language model scores which has the highest score is provided to a predecessor arc, and then the bigram
25 language score provided to the arc is added as a language model score of the hypothesis present on a certain arc.

The conventional speech recognition system has the following problems.

The first problem resides in that, when look-ahead of a bigram language model score is performed, a great memory capacity and a large amount of calculation are required.

The reason is that, where look-ahead of a bigram language model score is performed, when a context is produced and a tree structure dictionary is produced newly, it is required to repeat processing of producing not part of a tree structure dictionary but an entire tree structure dictionary, calculating all bigram language model scores with respect to the context and provide language model scores of all terminal arcs in the tree structure dictionary, with which words are settled, to a predecessor arc to propagate the language model scores to all predecessor arcs.

The second problem resides in that, when look-ahead of a unigram language model score is performed, wasteful calculation is performed.

The reason is that, when look-ahead of a unigram language model score is performed, some of arcs of a tree structure dictionary may expand only to a word whose connection to the context is not permitted linguistically and the hypothesis is expanded also to such arc, in which wasteful calculation is involved.

The third problem is such as follows. If strict look-ahead of a language model score of a bigram or more is

not performed using a frame synchronous beam search (for the frame synchronous beam search, for example, Hermann Ney, "Data Driven Search Organization for Continuous Speech Recognition", IEEE TRANSACTIONS ON SIGNAL PROCESSING, February, 1992 is referred to), that is, if connection possibility according to linguistic restrictions between a context and a word in a tree structure dictionary is not looked ahead, then the hypothesis is expanded also to an arc which is developed to a word whose connection to a context is not permitted linguistically as described above in connection with the second problem.

Then, if the score of the hypothesis is much higher than the others, then all hypotheses on an arc which is developed to a word whose connection to the context is permitted linguistically are excluded from the beam and thus eliminated.

As a result, in the succeeding frames, the word cannot be connected to a next word at all, and recognition processing for speech uttered later is disabled. In other words, recognition processing cannot be performed any more and a recognition result cannot be outputted.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a continuous speech recognition apparatus and method by which the recognition speed and the recognition accuracy in continuous speech recognition can be augmented.

In order to attain the object described above, according

to an aspect of the present invention, there is provided a continuous speech recognition apparatus, comprising a hypothesis storage section for storing hypotheses therein, hypothesis expansion discrimination means for determining
5 whether or not a hypothesis may be expanded to a succeeding arc, a tree structure dictionary storage section for storing a tree structure dictionary and a context preceding to the tree structure dictionary therein, a succeeding word speech part information storage section for storing information of whether
10 or not speech parts are included in all of succeeding words present behind each of arcs in the tree structure dictionary, a speech part connection information storage section for storing connection information between the speech parts, means for providing a language model score to a hypothesis, means
15 for providing an acoustic model score to a hypothesis, and hypothesis expansion means operable in response to an expansion instruction received from the hypothesis expansion discrimination means for acquiring a structure of an arc from the tree structure dictionary storage section and expanding
20 a hypothesis present on the arc to a succeeding arc taking the acoustic model score and the language model score into consideration and then storing a result of the expansion into the hypothesis storage section.

According to another aspect of the present invention,
25 there is provided a continuous speech recognition method for a continuous speech recognition apparatus which includes a

hypothesis storage section for storing hypotheses therein, a
tree structure dictionary storage section for storing a tree
structure dictionary and a context preceding to the tree
structure dictionary therein, a succeeding word speech part
5 information storage section for storing information of whether
or not speech parts are included in all of succeeding words
present behind each of arcs in the tree structure dictionary,
and a speech part connection information storage section for
storing connection information between the speech parts,
10 comprising the step of repeating a process for all of hypotheses
present at a certain frame time, the process including the steps
of acquiring a context of a tree structure dictionary to which
a hypothesis belongs from the tree structure dictionary storage
section, acquiring speech part connection information of the
15 speech parts of the context from the speech part connection
information storage section, acquiring arcs in the tree
structure dictionary to which the hypothesis belongs from the
hypothesis storage section, and repeating, for all succeeding
arcs immediately succeeding the arcs, a process including the
20 steps of acquiring, where an arc selected at present is
represented as first arc and a succeeding arc immediately
succeeding the first arc is represented as second arc,
succeeding word speech part information of the second arc from
the succeeding word speech part information storage section,
25 discriminating from the acquired speech part connection
information and the acquired succeeding word speech part

information whether or not the hypothesis may be expanded from the first arc to the second arc and determining that the hypothesis must not be expanded to the second arc if a connectable speech part included in the speech part connection information is not detected behind the second arc, but
5 determining otherwise that the hypothesis may be expanded to the second arc, expanding the hypothesis to the second arc. and discriminating whether or not the loop has been completed for all of the hypotheses and ending, when the loop has been
10 completed for all of the hypotheses, the expanding processing of the hypotheses of the frame in a frame synchronous beam search.

With the continuous speech recognition apparatus and method, a hypothesis is prevented from being expanded to an
15 arc to a word which cannot connect linguistically to a context. Consequently, the number of unnecessary hypotheses is minimized and the speed of continuous speech recognition is augmented as much. Further, occurrence of a situation that the score of a hypothesis to a word which cannot connect
20 linguistically to a context is higher than those of the other hypotheses is prevented. Consequently, the recognition accuracy in continuous speech recognition is augmented.

The above and other objects, features and advantages of the present invention will become apparent from the following
25 description and the appended claims, taken in conjunction with the accompanying drawings in which like parts or elements are

denoted by like reference symbols.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a continuous speech
5 recognition apparatus to which the present invention is
applied;

FIG. 2 is a diagrammatic view schematically showing an
example of a tree structure dictionary used in the continuous
speech recognition apparatus of FIG. 1;

10 FIG. 3 is a diagrammatic view illustrating an example
of succeeding word speech part information in the continuous
speech recognition apparatus of FIG. 1;

FIG. 4 is a diagrammatic view showing an example of speech
part connection information to a particle used in the
15 continuous speech recognition apparatus of FIG. 1;

FIG. 5 is a flow chart illustrating operation of the
continuous speech recognition apparatus of FIG. 1; and

FIG. 6 is diagrammatic view showing a conventional speech
recognition apparatus.

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DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows a continuous speech recognition apparatus
to which the present invention is applied. The continuous
speech recognition apparatus uses a frame synchronous beam
25 search. In the following description, only operation of
expansion of a hypothesis for one frame in a frame synchronous

beam search is described. The other operation of the continuous speech recognition apparatus conforms with that of a frame synchronous beam search.

Referring to FIG. 1, the continuous speech recognition apparatus shown includes a hypothesis storage section 1 for storing hypotheses to be used in a search of continuous speech recognition, and a tree structure dictionary storage section 4 for storing contexts and all words which make an object of recognition as tree structure dictionaries (refer to FIG. 2). The tree structure dictionaries are stored separately for the individual contexts.

A succeeding word speech part information storage section 5 stores speech part information of all succeeding words of each arc of a tree structure dictionary. As a manner of storing speech part information, it may be stored as a bit train including bits of "1" and "0" representing presence and absence of speech parts as a next speech part, for example, in the descending order of the speech parts in the frequency of appearance. If 256 different speech parts are available, a storage capacity of 256 bits is required for each arc. It is to be noted that succeeding word speech part information need not be stored for all arcs.

The succeeding word speech part information is required to be stored only for an arc immediately succeeding each node as denoted by 12 in FIG. 2. This is because an arc which does not immediately succeed a node must have succeeding word speech

part information quite same as another arc immediately preceding to the arc.

By storing succeeding word speech part information only of arcs immediately succeeding nodes into the succeeding word
5 speech part information storage section 5 in this manner, the required memory capacity can be reduced.

The succeeding word speech part information of each arc of a tree structure dictionary is required to be produced and stored only once before recognition processing is executed.
10 This is because, when recognition processing is executed, the number of words succeeding an arc does not increase or decrease and does not change at all.

Further, also when additional registration of a word is performed to add the word to a tree structure dictionary, the
15 succeeding word speech part information of each arc is required to be reproduced and stored only once.

In contrast, when look-ahead of a bigram is performed, each time a context is determined and a tree structure is produced, calculation of all bigram language models with
20 respect to the context and propagation of provision of language model scores to predecessor arcs must be performed, and therefore, a very large amount of calculation is required.

The succeeding word speech part information is required to be stored by only one piece for each arc, different from
25 a tree structure dictionary which is stored separately for each context.

This is because, if succeeding word speech part information regarding each arc on a tree structure dictionary becomes required, then it is only required to refer to the succeeding word speech part information which is stored by only
5 one piece regarding the arc.

Where look-ahead of a bigram is performed, since it is required to store a bigram language model score for each arc of all tree structure dictionaries, a memory of a very large storage capacity is required. However, in the embodiment of
10 the present invention, since it is only required to store a number of bit trains equal to the number of speech parts for one tree structure dictionary, the required memory capacity is reduced significantly.

Where speech parts appear in the descending order in appearance frequency of "particle", "noun", "verb" and
15 "adjective", a bit train of such a sequence that the first bit of the speech part information of a succeeding word represents that a particle is present (1)/absent (0); the second bit represents that a noun is present (1)/absent (0), ... is stored.

It is to be noted that, although the succeeding word speech part information need not necessarily be stored in the descending order of speech parts in appearance frequency, in the following description, it is assumed that the succeeding word speech part information is stored in the descending order
20 of speech parts in appearance frequency.

FIG. 3 illustrates an example of a bit train of succeeding

word speech part information when, where the descending order of speech parts in appearance frequency is the particle, noun, verb and adjective, succeeding words of a certain arc include a "particle", a "noun" and an "adjective", but do not include a "verb".

A speech part connection information storage section 6 stores information of all speech parts which can succeed each speech part on the right side. As a manner of storage of the speech information, for example, succeeding speech parts are stored as a bit train including bits of 1 representing that connection is allowed and 0 representing that connection is not allowed in the descending order of speech parts in appearance frequency similarly to the succeeding word speech part information storage section 5.

FIG. 4 illustrates an example of a speech part connection information bit train of a "particle" when a "particle" and a "verb" connect but a "noun" and an "adjective" do not connect to the right side of the "particle" where the descending order of the speech parts in appearance frequency is the "particle", "noun", "verb" and "adjective".

A hypothesis expansion discrimination section 2 receives a context of a tree structure dictionary on which a certain hypothesis is present from the tree structure dictionary storage section 4, receives succeeding word speech part information of an arc immediately succeeding the arc which has the hypothesis, and receives speech part connection

information of speech parts which can connect to the right sides
of the speech part to which the context received belongs, and
then determines from the succeeding word speech part
information and the speech part connection information whether
5 or not the hypothesis may be expanded to the succeeding arc.

Where the succeeding word speech part information and
the speech part connection information are such as illustrated
in FIGS. 3 and 4, respectively, in order to determine whether
or not the hypothesis may be expanded to the succeeding arc,
10 the bit train shown in FIG. 3 and the bit train shown in FIG. 4
should be logically ANDed in a unit of a bit, and it should
be checked whether or not a result of the operation is "0".

If the result of the operation is not "0", then this
signifies that the hypothesis may be expanded to the succeeding
15 arc, but if the operation result is "0", then this signifies
that the hypothesis must not be expanded to the succeeding arc.

The reason is that, where the Nth (N is an integer equal
to or greater than 0) bit of the speech part connection
information is "1", only when the Nth bit of the succeeding
20 word speech part information is "1", a word of a speech part
whose connection is permitted is present succeeding the arc
and the logical AND of them does not become "0".

For example, where 256 different speech parts are
involved, if the computer has a 32-bit CPU, then $256/32 = 8$
25 operations are required in order to logically AND all of the
succeeding word speech part information and the speech part

connection information.

On the other hand, where the order in which speech parts are stored is set to the descending order of the speech parts in appearance frequency, the expected value of the number of operations required to obtain a result of the logical AND which is not "0" can be suppressed smaller than 8.

In this manner, to store succeeding word speech part information and speech part connection information in the descending order of speech parts in appearance frequency contributes to high speed operation. It is to be noted that naturally it is possible to store succeeding word speech part information and speech part connection information alternatively in any other order than the descending order of speech parts in appearance frequency and perform connection checking of speech parts corresponding to each other.

It is to be noted that, if a hypothesis is expanded already to an arc immediately succeeding another arc which belongs to the hypothesis, then since it must have been determined in the past that connection is permitted, the hypothesis may be expanded to the succeeding arc unconditionally.

Based on the criterion described above, the hypothesis expansion discrimination section 2 instructs the hypothesis expansion section 3 that expansion of the hypothesis to the succeeding arc is permissible/not permissible.

The hypothesis expansion discrimination section 2 receives an instruction of expansion of the hypothesis to the

succeeding arc, acquires a structure of the arc to the succeeding arc from the tree structure dictionary storage section 4 taking scores given thereto from the language model section 7 and the acoustic model section 8 into consideration, and expands the hypothesis only to the arc, to which the hypothesis may be expanded, in accordance with a frame synchronous beam search. It is to be noted that expansion of the hypothesis to the arc itself may be performed unconditionally.

10 This signifies that, for example, that a hypothesis is present on a certain arc signifies that expansion of the hypothesis to the arc has been permitted in the past.

As described above, in the continuous speech recognition apparatus of the present embodiment, look-ahead of the connection possibility between a linguistic context and words in a tree structure dictionary is performed.

15 The present invention is effective unless exact look-ahead of a language model score more than a bigram by which the connection possibility between a context and words in a tree structure dictionary can be looked ahead, and a very large amount of calculation or memory capacity for the look-ahead of a bigram language model score is not required.

FIG. 5 illustrates operation in expansion of a hypothesis for one frame of a frame synchronous beam search.

25 Referring to FIG. 5, first in step S1, a loop (repetitive processing) regarding all hypotheses which are present at a

certain frame time is started.

In step S2, a context of a tree structure to which a hypothesis belongs is acquired from the tree structure dictionary storage section 4.

5 In step S3, speech part connection information of speech parts of the context is acquired from the speech part connection information storage section 6.

In step S4, an arc in the tree structure to which the hypothesis belongs is acquired from the hypothesis storage section 1. The arc acquired at this time is set as "arc 1".

In step S5, a loop regarding all succeeding arcs directly succeeding the "arc 1" is started. A directly succeeding arc selected now is set to "arc 2".

15 In step S6, succeeding word speech part information of the "arc 2" is acquired from the succeeding word speech part information storage section 5.

In step S7, it is determined from the speech part connection information acquired in step S3 and the succeeding word speech part information acquired in step S6 whether or not the hypothesis may be expanded from the "arc 1" to the "arc 2". If a connectable speech part included in the speech part connection information is not detected behind the "arc 2", then it is determined that the hypothesis must not be expanded to the "arc 2", and the control branches to step S9. Otherwise, 25 it is determined that the hypothesis may be expanded to the "arc 2", and the control advances to next step S8.

In step S8 (processing by the hypothesis expansion section 3), the hypothesis is expanded to the "arc 2" in accordance with the determination in step S7.

5 In step S9, it is determined that the processing of the loop regarding all of the arcs is completed. If the processing is completed, then the control advances to step S10, but otherwise, the control returns to step S5.

10 In step S10, it is determined whether or not the processing of the loop regarding all of the hypotheses is completed. If the processing is completed, then the expansion processing of the hypotheses of the frame in the frame synchronous beam search is ended. If the processing of the loops regarding all of the hypotheses is not completed, then the control returns to step S1. It is to be noted that the
15 processing steps described above with reference to FIG. 5 may be implemented by executing a speech recognition program (software) stored in a memory of a computer (CPU) which forms the speech recognition apparatus. In this instance, the continuous speech recognition method of the present invention
20 can be carried out by reading out the program from a storage medium such as a floppy disc, a CD-ROM or a non-volatile memory, loading the program into the memory and executing the program by means of the CPU.

25 While a preferred embodiment of the present invention has been described using specific terms, such description is for illustrative purposes only, and it is to be understood that

changes and variations may be made without departing from the spirit or scope of the following claims.

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